Detailed Calculations of the Properties of Three-Nucleon Bound States(Abstracts of Doctral Dissertations)

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journal or publication title	The science reports of the Tohoku University. Ser. 8, Physics and astronomy
volume	13
number	2/3
page range	199-200
year	1993-01-31
URL	http://hdl.handle.net/10097/25791

Detailed Calculations of the Properties of Three-Nucleon Bound States

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Abstract

The effects of the Coulomb force, charge independence breaking (CIB) and charge symmetry breaking (CSB) nuclear forces, and $\pi\pi$, $\pi\rho$, and $\rho\rho$ exchange three-nucleon forces on the binding energies of ^{3}H and ^{3}He are studied in detail by solving Coulomb-modified Faddeev equations for various realistic NN potentials. 52-channel calculations are performed for the first time in order to get convergent and reliable results. Our calculation results may be summarized as follows.

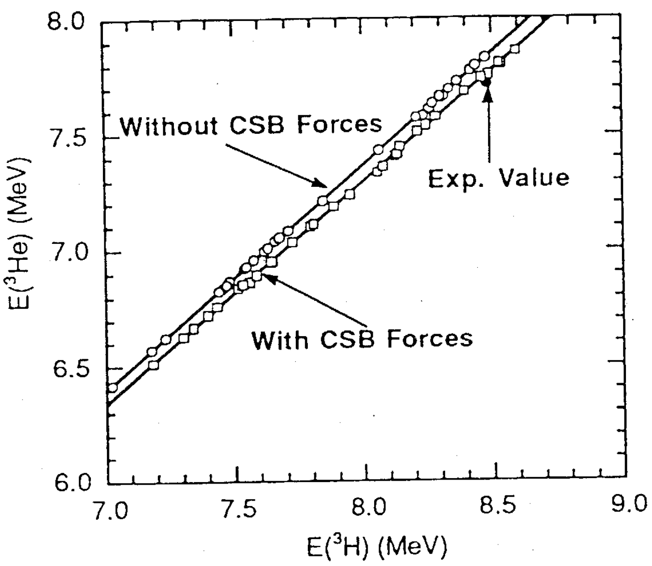

FIG. 1. The binding energies of ^{3}He with the Coulomb force, with or without the CSB forces plotted against the binding energies of ^{3}H for diverse 2NP, 3NP and channels of three-body system.

TABLE I. The contributions of charge asymmetric effects to the ^{3}H and ^{3}He binding energy difference in keV.

Charge asymmetry effects	δE
Static Coulomb ($E_{C,MI}$)	648 ±4
Magnetic interaction	10 ±1
Vacuum polarization	4
Orbit-orbit interactions	9 ±1
K. E. due to n-p mass diff.	11
δE_{other}	34 ±2
CIB and CSB forces ($^1S_0$)	75 ±7
CSB other than $^1S_0$	2
Uncertainty from $V_{phe.}$	1 ±1
$\delta E_{\rm CSB}$	78 ±8
Total (theory)	760 ±14
Experiment	764

[1] First, we calculated the binding energies of the trinuclei. After 32 case studies, we found a very good linear relationship between ^{3}H and ^{3}He binding energies (see Fig. 1), from which we deduce a model independent value for the Coulomb-energy difference, 648±4 keV with finite-size proton. As for the effects of CIB and CSB nuclear forces,

we found that the effect of CIB contributes about 0.1-0.2 MeV to the binding energies of trinuclei. On the other hand, the effect of CSB contributes 75±7 keV to the binding energy difference (see Fig. 1). With other small effects, these reasonably account for the ^{3}H-^{3}He binding energy difference (see TABLE 1).

[2] In addition to 2π exchange three-nucleon forces, we considered also three-nucleon forces with $\pi\rho$, $\rho\rho$ exchange and K.R. term. We found that the binding energies of ^{3}H and ^{3}He can be reproduced with some reasonable sets of values of Λ_π, and Λ_ρ. Among them, the set $\Lambda_\pi = 0.81$ GeV and $\Lambda_\rho = 1.13$ GeV yields the triton binding energy of 8.485 MeV (experimentally, 8.482 MeV) and the Gamow-Teller matrix element of $0.955\sqrt{3}$ (experimentally, $(0.962\pm0.002)\sqrt{3}$) in the triton β-decay.

[3] Using the wave functions obtained from Faddeev partial-wave calculations, we investigated the bound state properties of trinuclei. For the percentage of the partial waves, we obtained about 90% of the space-symmetric S-state. The D-state caused by the tensor forces in the NN interactions is about 10%. The small but nevertheless important S'-state arised from the spin- and isospin-dependence of the NN interactions is about 1%. We found that the Coulomb force makes decrease the percentage both for the S-state and the D-state but does increase the S$'$-state percentage in ^{3}He compared with ^{3}H. Because of the Coulomb force CIB and CSB nuclear forces, the isospin $T = 3/2$ component is mixed in the wave functions of trinuclei. However, its percentage is only about 10^{-3}%, so we can omit it in most of the calculations.

[4] For asymptotic normalization constants, we got the relation $C_0^c \approx C_0$ for the S-wave. However, for the D-wave the Coulomb effect makes decrease the asymptotic normalization constants of ^{3}He compared with that of ^{3}H by about 5%. We also obtained a good linear relationship between the ratio $\eta = C_2/C_0$ and the binding energies of trinuclei and the experimental ratio η are reproduced well at the binding energies of trinuclei.

[5] We investigated the charge form factors of ^{3}H and ^{3}He. By including meson exchange currents: the π-, ρ- and ω-pair currents, the $\rho\pi\gamma$ and the $\omega\pi\gamma$ mixing currents, the π-, ρ- and ω-retardation currents, we reproduced the experimental date very well, especially for triton. We also calculated the charge radius of ^{3}H and ^{3}He from the charge form factors and found $r_c(^3H) = 1.725 \pm 0.007$fm (experimentally, 1.68 ± 0.03fm) and $r_c(^3He) = 1.958 \pm 0.006$fm (experimentally, 1.978 ± 0.015fm).

[6] As an extended calculation, we generalized the Faddeev equation approach to a system with distinguishable particles. It was applied to the three-nucleon systems by taking neutron and proton as distinguishable particles because of their mass difference. We obtained 13 keV difference in the binding energy of ^{3}H and ^{3}He due to the n-p mass difference. By the success of solving the three-nucleon systems of this kind, we hope to apply the same formalism to other physical systems, such as hypertriton $^3_\Lambda H$, in a near future.